

Geophysics

Aim:

**To provide theoretical information about:
definition of terms, surface waves, body
waves, signal theory, reflection,
refraction, diffraction, amplitudes and the
decibel scale.**

At the end of this Session, you will be able to:

- **Define the term elastic deformation.**
- **Define the term raypath.**
- **Describe a wave based on wavelength, period, wavenumber, frequency, amplitude, peak and trough.**
- **State the mathematical relationship between frequency, wavelength and velocity.**
- **State the mathematical relationship between period and frequency.**

At the end of this Session, you will be able to:

- **Define the terms surface wave, body wave, spherical divergence, cylindrical divergence, P wave, S wave, Rayleigh wave and Love wave.**
- **Produce a diagram that shows direction of particle motion that characterizes each of the above 4 wave types.**
- **Describe and compare the velocity of the above 4 waves types.**
- **State the observed range of P-wave velocity for each of the following: air, water, sandstone, limestone, shale, granite, salt**

At the end of this Session, you will be able to:

- **Define Huygen's Principle.**
- **Define the terms reflection, refraction, critical angle, mode conversion, reflection coefficient, transmission coefficient and acoustic impedance.**
- **State Snell's Law.**
- **Produce a diagram that shows Snell's Law in terms of incident, reflected and refracted ray paths and angles.**
- **Define the terms diffraction, ghost, multiple.**

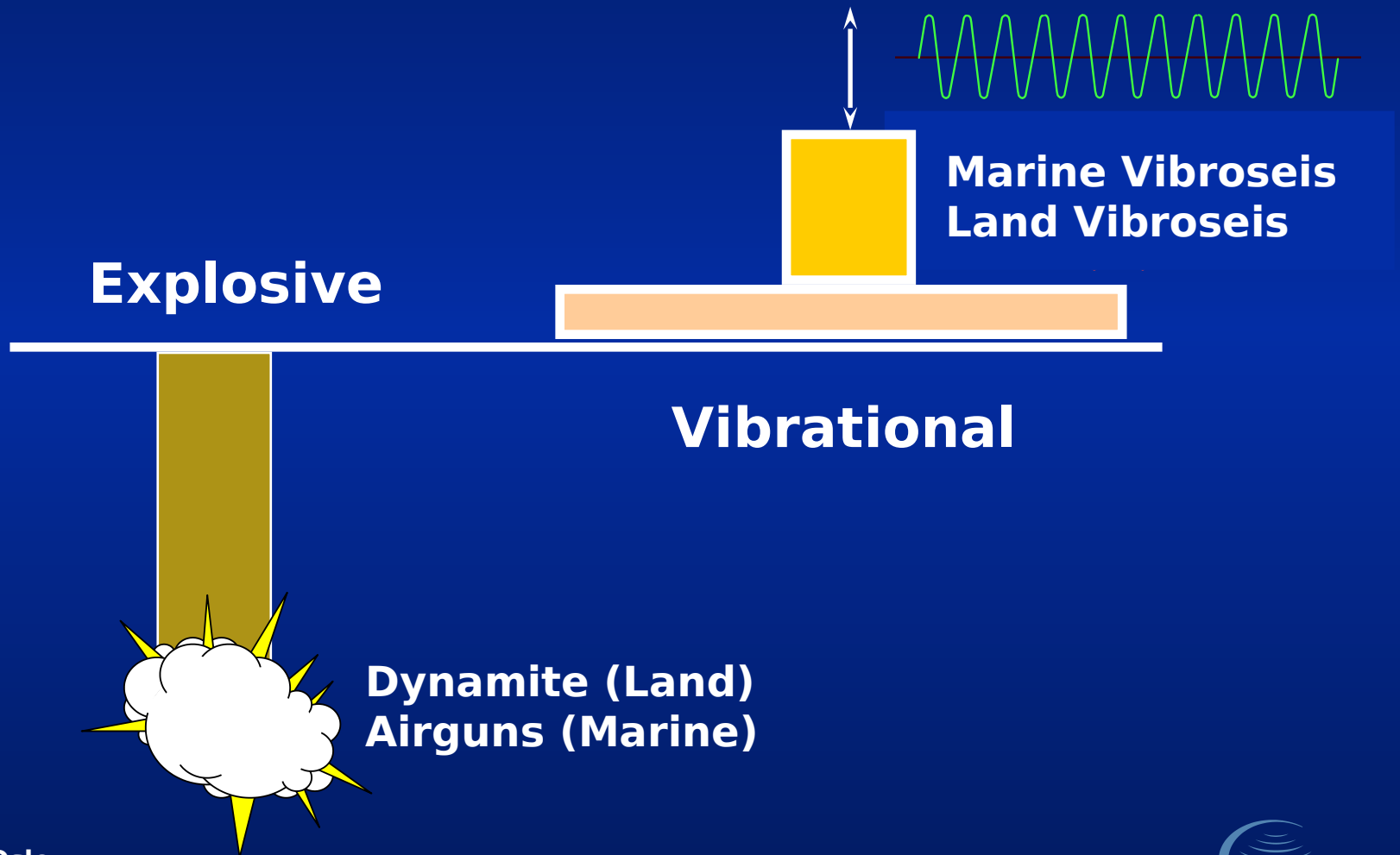
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Waves

- **Whenever an acoustic source is detonated on or near the surface of the Earth, an acoustic wave is produced that propagates away from the source.**
- **The waves are said to cause 'elastic' deformation consisting of alternating compressions and dilations of the particles in the material.**
- **Apart from effects very close to the source, this wave moves through the medium without causing a net movement of the material - the medium (more or less) returns to its normal state once the wave has passed through.**

Seismic Waves - Generation



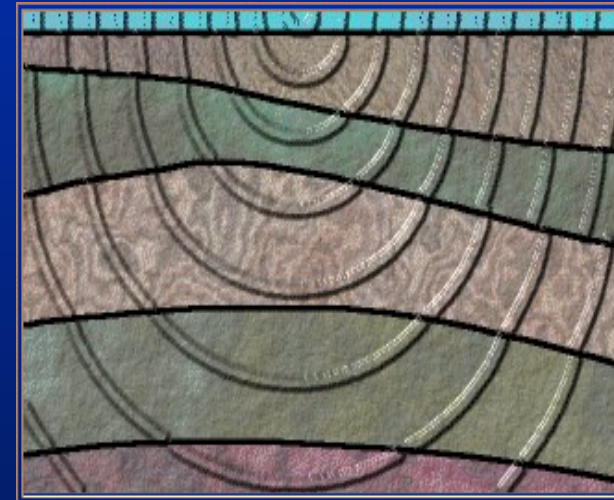
Waves

- **The displacement of the particles is oscillatory about their undisturbed locations.**
- **The nature of the displacement classifies the type of wave that is passing.**
- **Waves can travel through a body (body waves), or along the surface of a body (surface or boundary waves).**

Wavefronts

- We can either consider the seismic energy as a wavefront, or as a series of rays emanating from the shot. Here's a cross-section view of the expanding wavefront in a simple geological model, as it appears at various times throughout the recording.

- The model assumes a constant velocity within each layer - in practice the velocity may change both vertical and laterally (in 3 dimensions!).



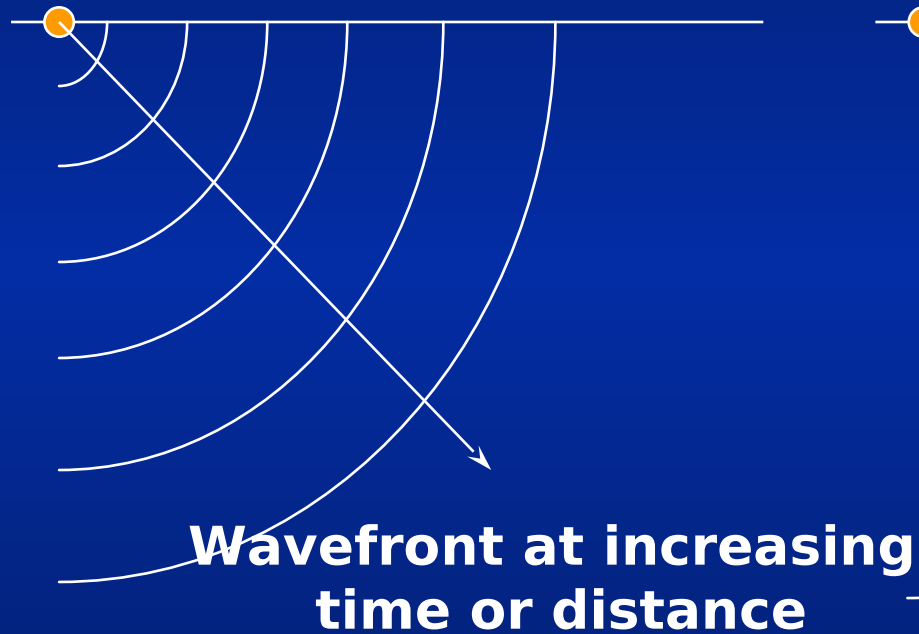
- The actual shape of the expanding wavefront can, therefore, become very complex,

Raypaths

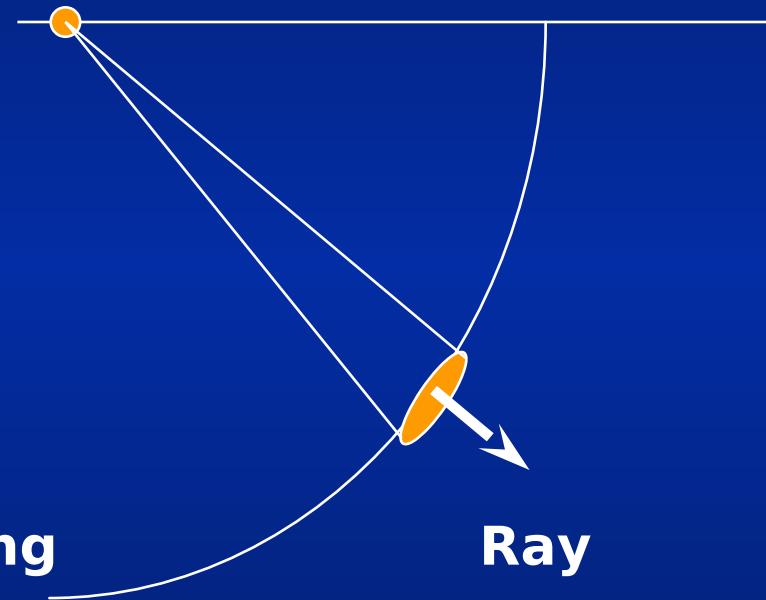
- **For simplicity's sake we don't deal with wavefronts we use raypaths.**
- **A line which is everywhere perpendicular to a wavefront is known as a ray**
- **Ray paths, or lines drawn on a cross-section showing the path of the energy from the shot to the receiver, are a useful way of showing the total travel-time of a seismic "ray".**

Wavefronts and Raypaths

Wavefronts



Raypaths



The Seismic Experiment

Source

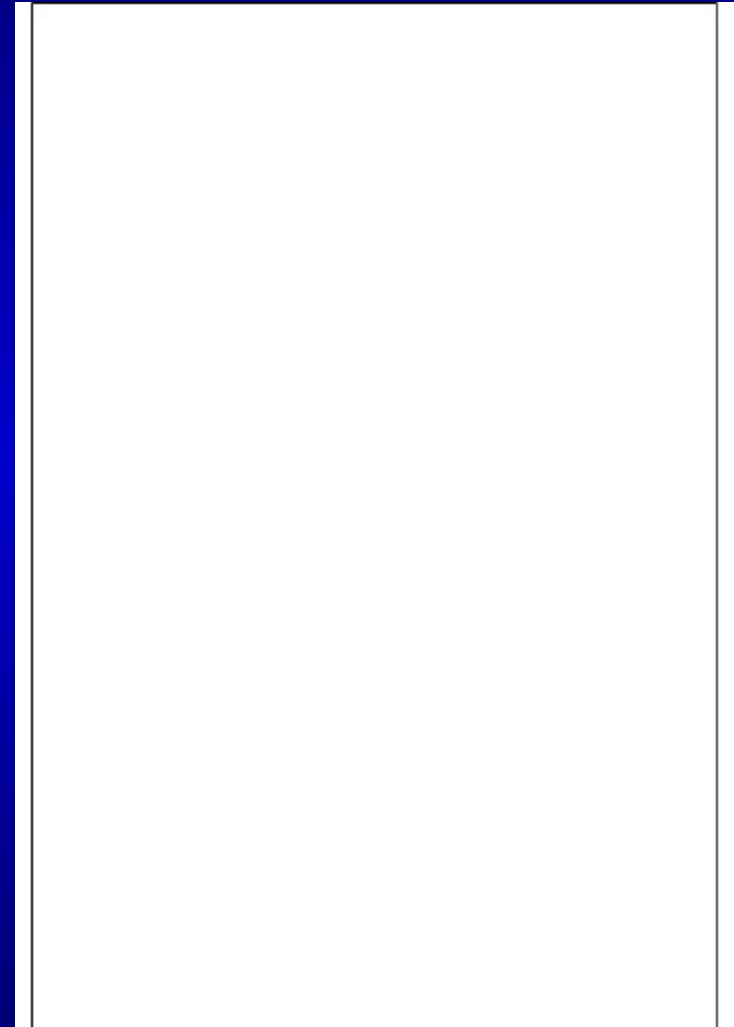
Receiver

Measure:

- Travel time
- Amplitude
- Particle motion

Infer:

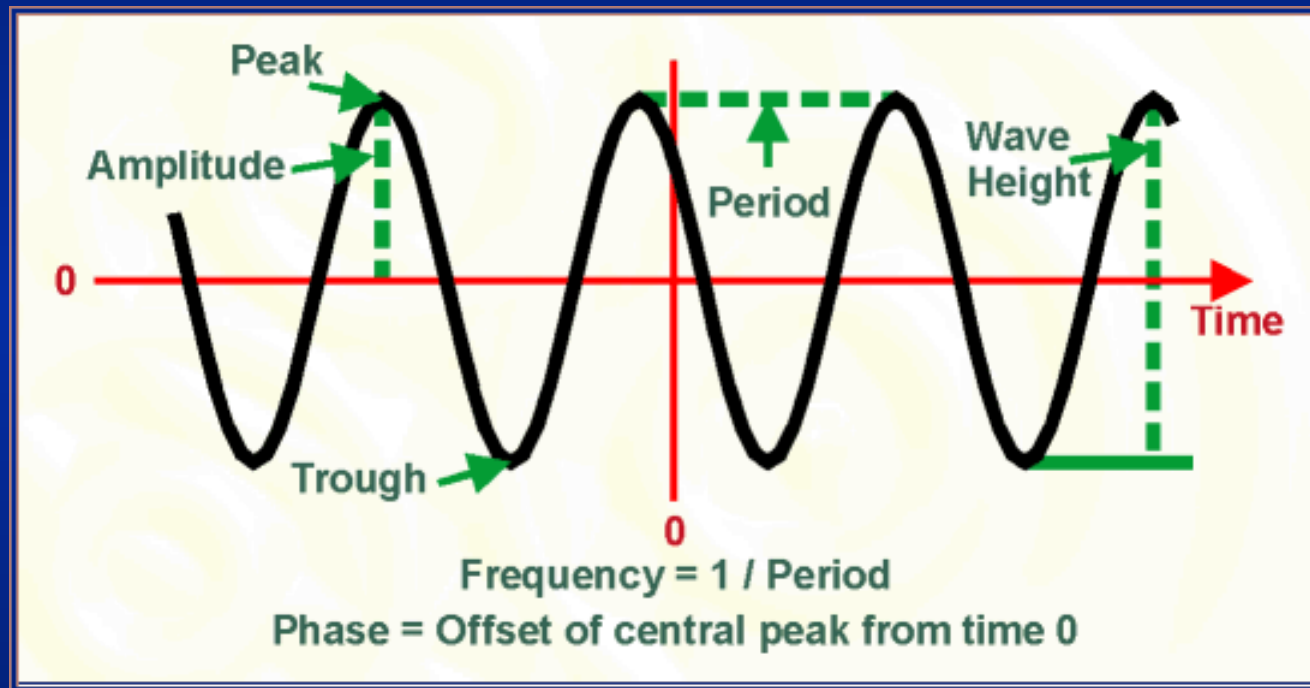
- Velocity



Midpoint

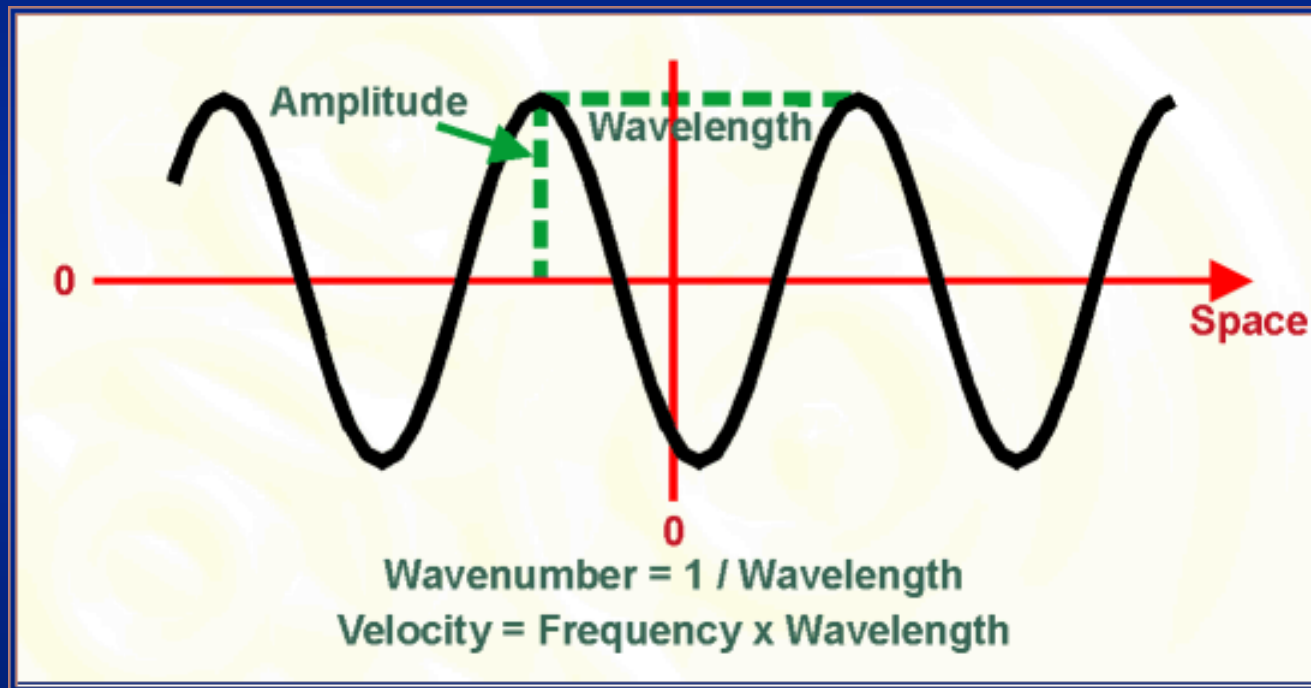
Parameters associated with a wave

Some parameters associated with a wave recorded as a function of time:



Parameters associated with a wave

A wave shown as a function of distance, has similar parameters



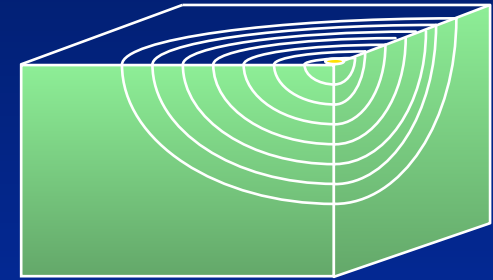
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Wave Types

- **Body waves**

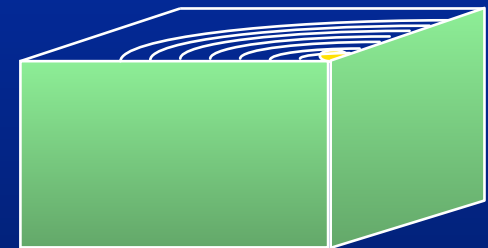
2 types of body waves are P and S waves. The energy of these waves decreases inversely proportional to the square of the distance travelled.



Spherical divergence

- **Surface Waves**

2 Types of Surface waves are Rayleigh and Love waves. The energy of these waves decreases inversely proportional to the distance travelled.



Cylindrical divergence

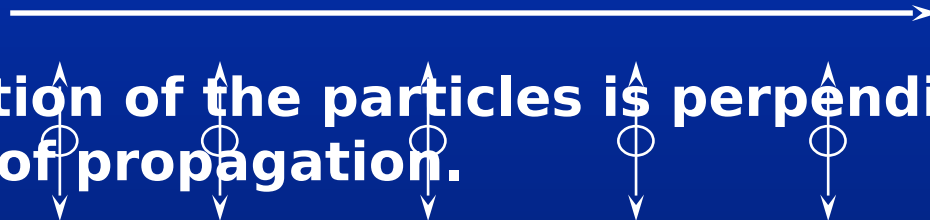
Body Waves

- There are 2 classes of body waves, classified by the particle motion
- P waves - motion of particles is parallel to the direction of propagation



- Wave direction
- Particle motion

- S waves - motion of the particles is perpendicular to the direction of propagation.



- Wave direction
- Particle Motion

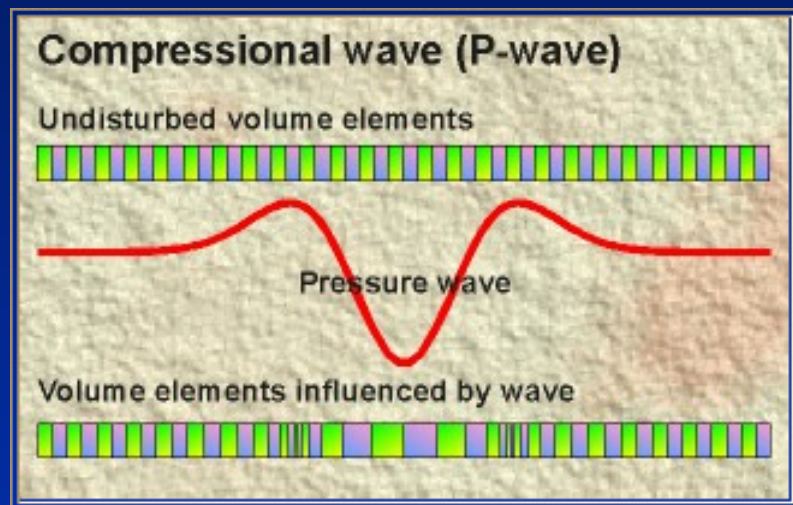
P Waves

- **Primary waves - named from earthquake seismology meaning the 'first arrival'. Also referred to as Compressional, Longitudinal, Push-pull, Pressure, Dilatational, Rarefaction and Irrotational wave**
- **Longitudinal particle motion.**
- **Compressional waves (zones of compression and rarefaction), just like ordinary sound waves in air.**
- **P waves have higher velocities than S waves.**
- **P waves are the predominant wave used in seismic prospecting. This is what we want to generate and record.**

S Waves

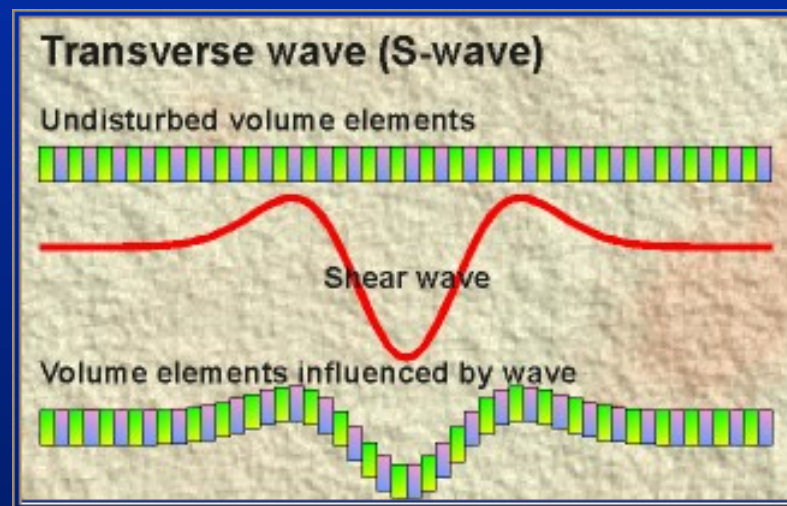
- **Secondary waves - named from earthquake seismology meaning secondary arrival. Also referred to as Shear, Transverse, Rotational, Distortional, Equivolumnar and Tangential wave**
- **Transverse particle motion.**
- **Velocity is approximately 0.5 x p-wave velocity.**
- **Not usually used in the seismic industry, mainly because they cannot propagate in fluids. S waves appear as noise overlaying P waves. In certain circumstances (e.g. Shallow surveying) shear waves may be deliberately generated.**
- **Shear waves may be SV (vertical particle motion) or SH (horizontal particle motion).**

P and S Waves



The pressure wave pushes the particles of material ahead of it, causing compression and expansion of the material.

A wave in which the particle motion is at right-angles to the direction of propagation is known as an S-Wave.



Surface Waves

ated with a surface or boundary. The amplitude decays rapidly with

- Rayleigh waves Love waves.
- Hydrodynamic waves Stoneley waves.
- Surface waves appear as noise overlaying P wave energy.
- Particle motion is general complex.
- e.g. Rayleigh waves have a retrograde elliptical motion.
- Surface waves generally have low velocity.
- e.g. Rayleigh wave velocity typically $0.9 \times S$ wave velocity.
- At the surface these are grouped together as **GROUND ROLL**.

Rayleigh and Love Waves

Rayleigh waves:

A type of seismic wave propagated along a free surface.

The dominant wave involved in ground roll.

Love waves:

A surface seismic wave associated with layering, characterized by horizontal motion perpendicular to the direction of propagation with no vertical motion.

They may also be thought of as channel waves with the earth's surface the upper channel boundary.

Particle Motion

- **P wave - compressional**

Wave Direction 

Particle Motion 

- **S wave - shear**

Wave Direction 

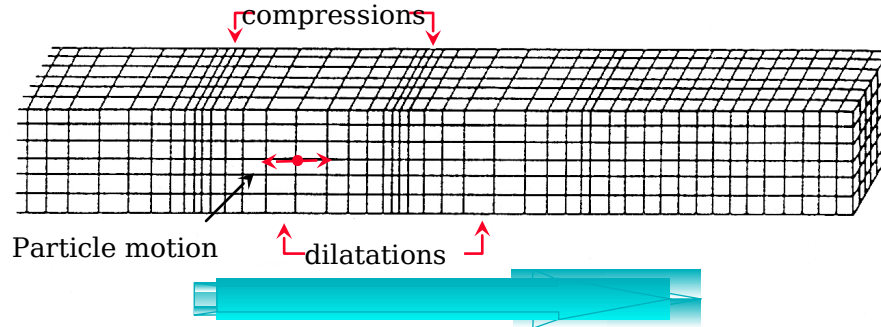
Particle Motion 

- **Surface wave - complex**

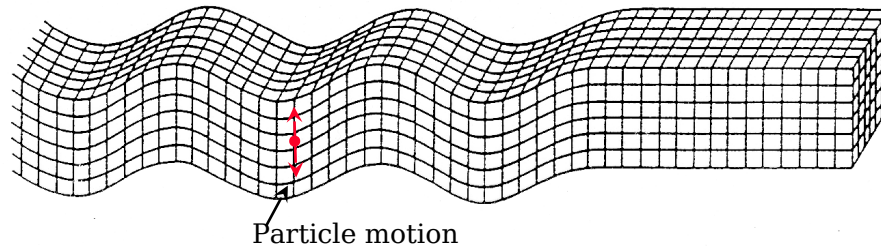
Particle Motion 

Elastic Deformations

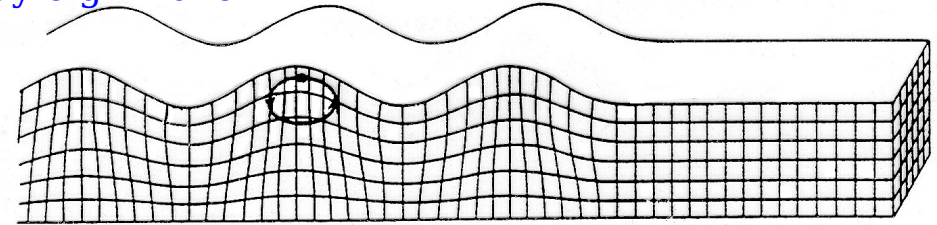
P - wave



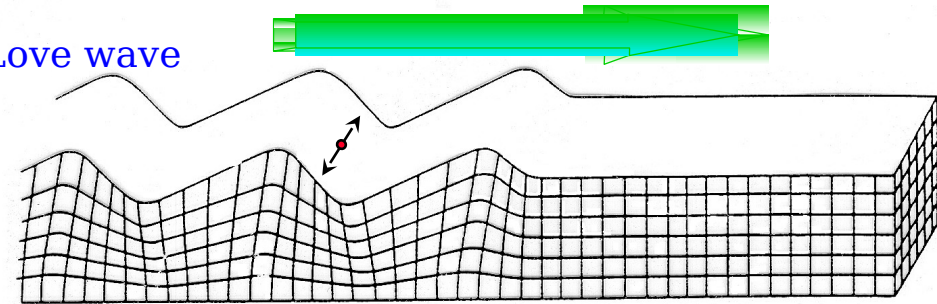
S - wave



Rayleigh wave



Love wave



Elastic deformations and ground particle motions associated with the passage of body waves

Elastic deformations and ground particle motions associated with the passage of surface waves

Wave Energy

On land with surface release the approximate energy division between different wave modes is :

Rayleigh.....	68%
Shear.....	26%
Compressional.....	6%

So, we are only approximately 6% efficient at producing the waves we require

Wave Velocity

Waves Velocities are a function of the elastic constants of the media in which they propagate

V_p and V_s are related to each other using σ

$$V_s/V_p = (0.5 - \sigma / 1 - \sigma)^{1/2}$$

For liquids $\sigma = 0.5$, no shear waves can propagate

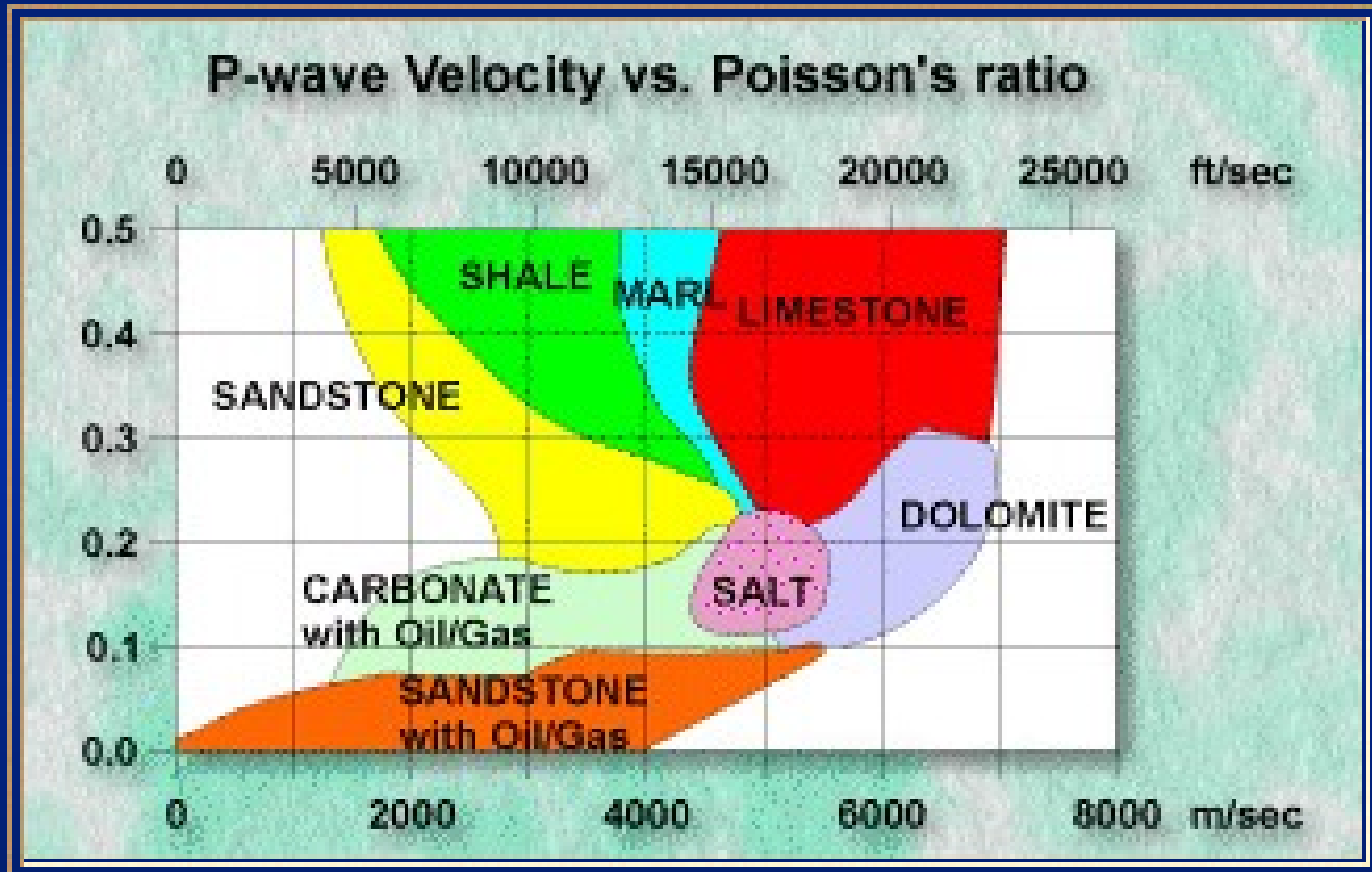
For solids $\sigma \sim 0.25$, so **$V_s \sim 0.5 \times V_p$**

σ = poissons ratio, elastic constant

Typical P-Wave Velocities

• Air	330m/s
• Water	1480m/s
• Sandstone	2900m/s
• Shale	3000m/s
• Salt	5000m/s
• Limestone	5500m/s

Typical P-Wave Velocities

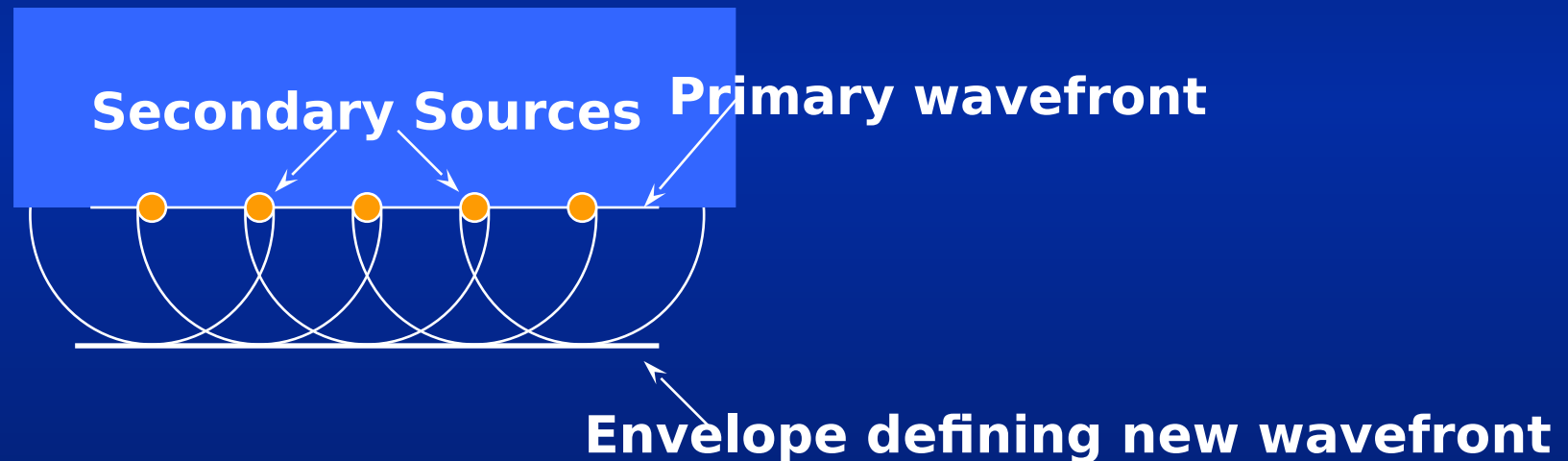


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Huygens Principle

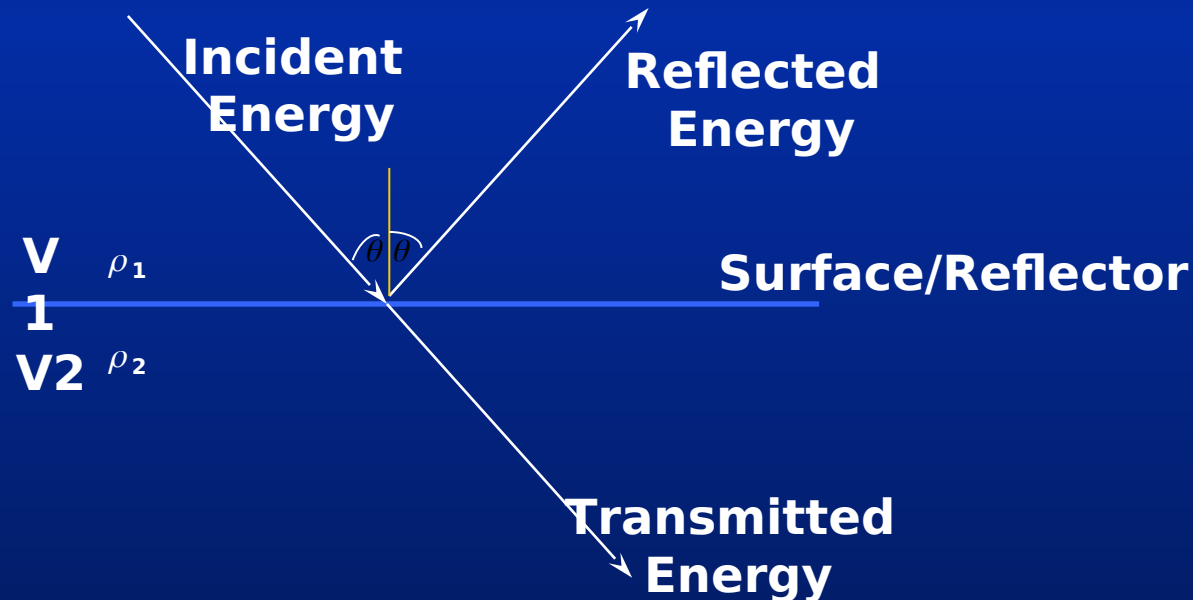
- Every point on a wavefront can be regarded as a secondary source of the wave.
- The envelope function defined by the secondary source wavefronts is the wavefront at a latter time (or further distance).



[Web Site](#)

Interfaces

- When acoustic energy impinges on an interface between two layers
- With different elastic properties within the earth two things can happen:
 - Energy is reflected
 - Energy is transmitted
- Ray theory gives the best visual representation



Reflections and Refractions

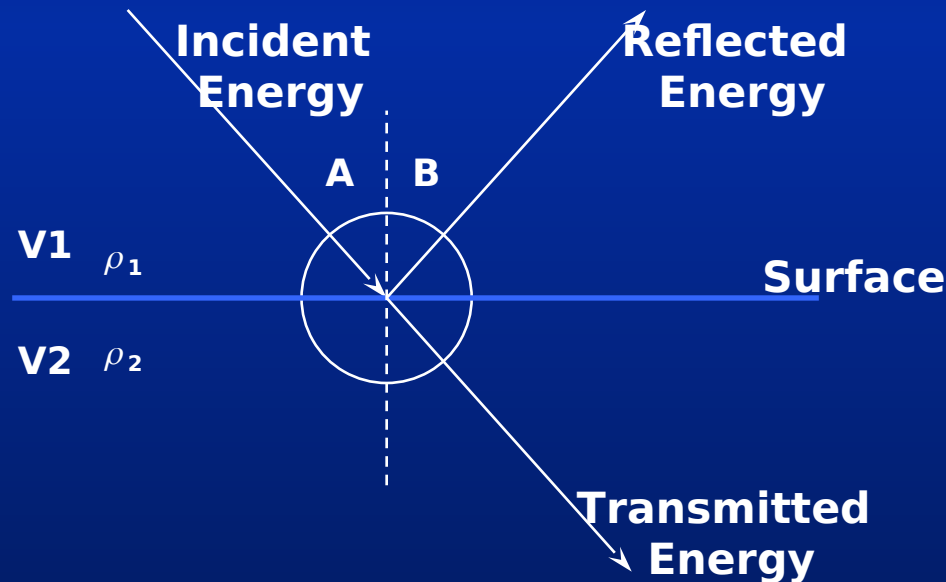
Reflection: The energy or wave from a seismic source which has been reflected from an acoustic impedance contrast (reflector) or a series of contrasts within the earth

Refraction: The change in direction of a seismic ray upon passing into a medium with a different velocity. The mathematics of this is defined by Snell's law.

Reflection

An elastic wave reflects from an interface at the same angle it strikes it

Angle of incidence A = Angle of reflection B

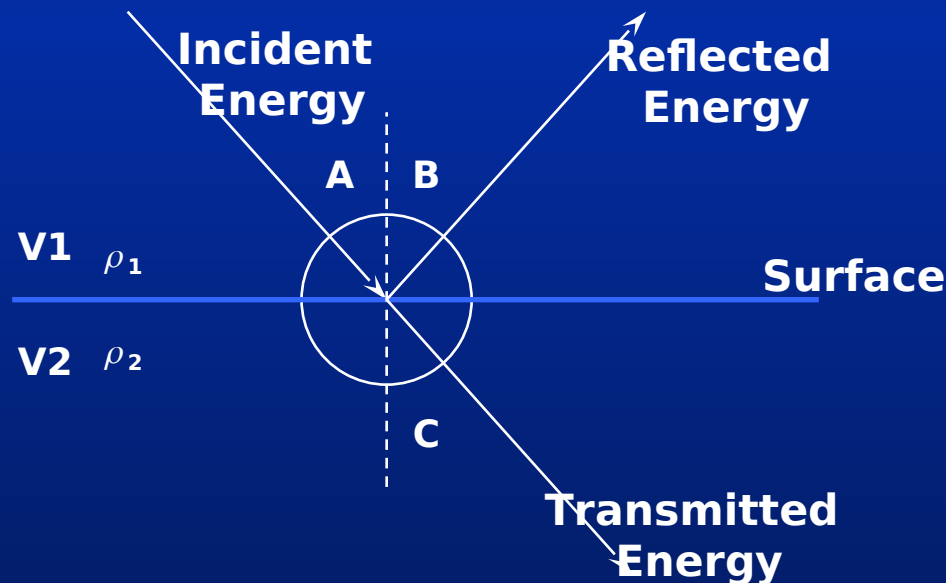


Refraction

When the layer velocity changes across an interface, the direction of propagation of the energy changes. This change is given by:

• **SNELL'S LAW**

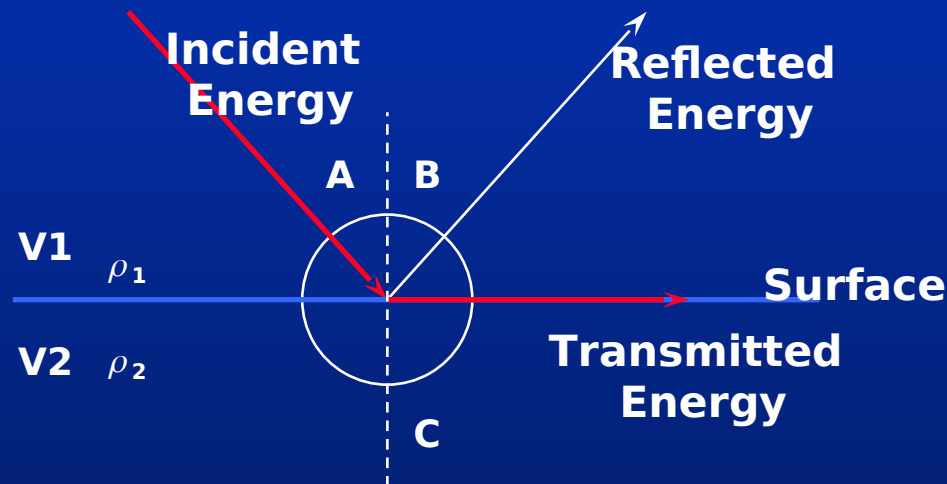
$$\frac{\sin A}{\sin C} = \frac{v_1}{v_2}$$



Critical Refraction

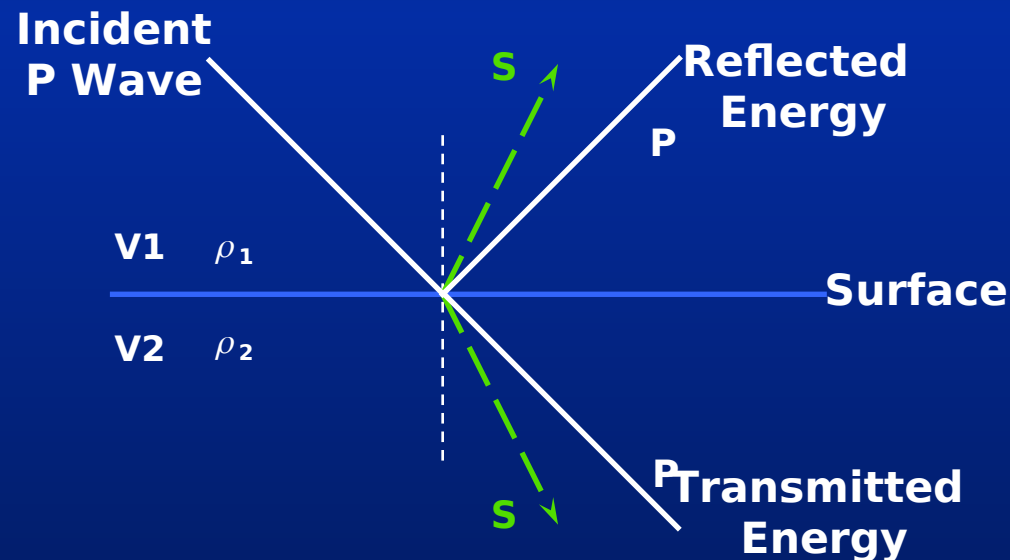
In the case that angle C = 90 degrees, the transmitted energy is **CRITICALLY REFRACTED** along the interface with the velocity V2

In this case Snells law leads to **Angle A is now the CRITICAL ANGLE,**
 $\sin A = v_1 / v_2$ the transmitted wave is now a Surface wave called the HEAD WAVE



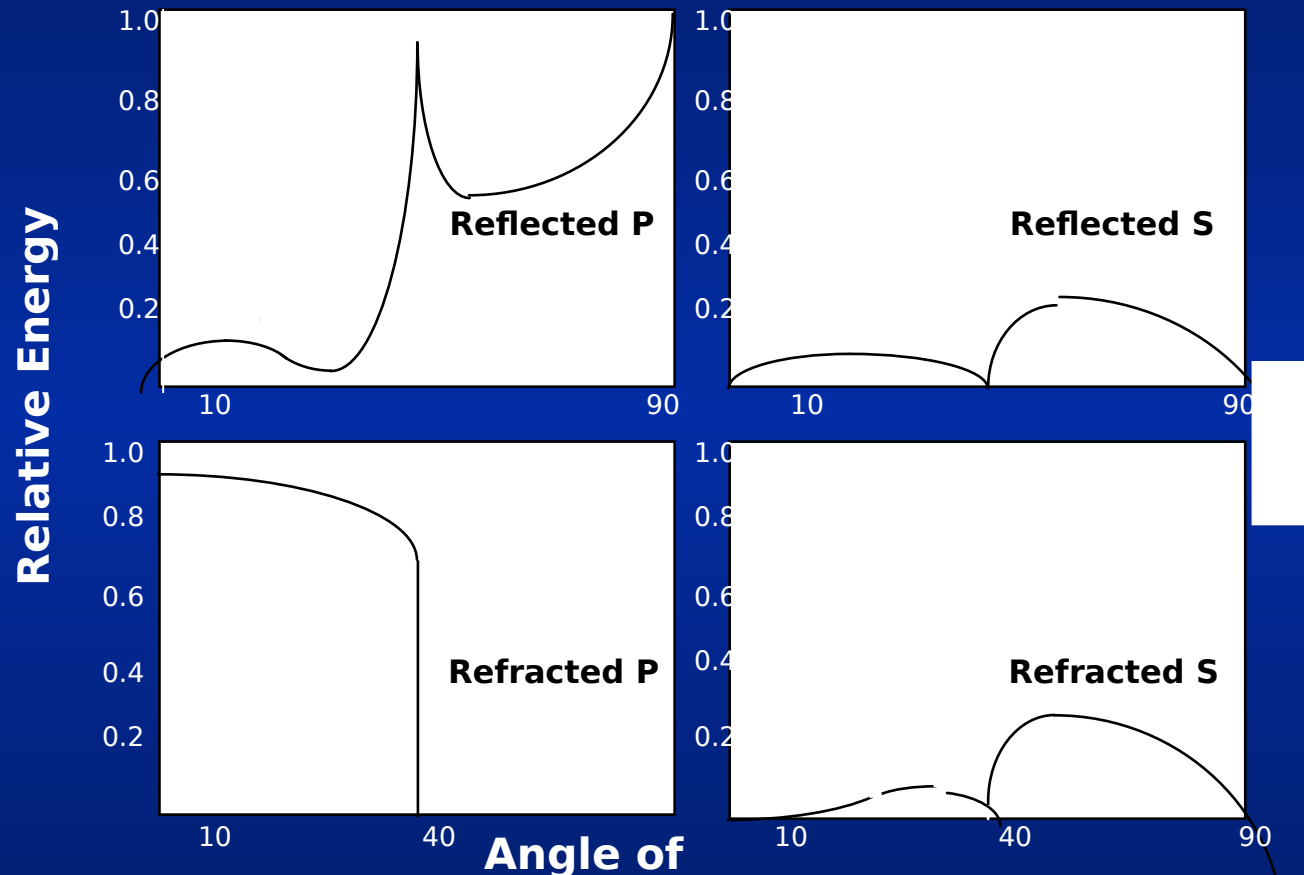
Mode Conversion

- When a wave strikes an interface at an angle greater than zero degrees, then mode conversion occurs. (any angle other than 90°)
- An incident P or S wave will generate transmitted P and S waves, and also reflected P and S waves.
- Mode conversion is only normally significant for large angles of incidence beyond those normally obtained in reflection seismic.



Interfaces - Mode Conversion

After Richards, interface between deep elastic formations and dense limestones



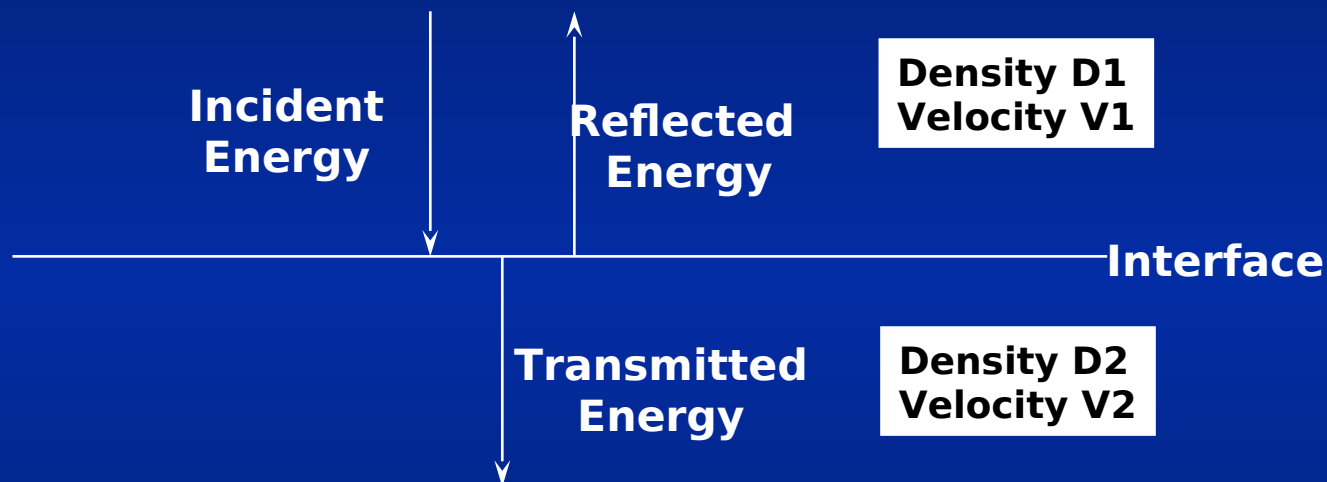
Surface conditions that conserve energy and momentum across the interface result in a set of equations - **ZOEPPRITZ EQUATIONS**

Reflection and Transmission Coefficient

- **Reflection Coefficient (reflectivity)** is the ratio of the amplitude of a wave reflected off an interface to that of the wave incident upon it. Its basically the percentage of energy that will be reflected.
- **Transmission Coefficient** is the ratio of amplitude of a wave transmitted through an interface to that of the wave incident upon it.

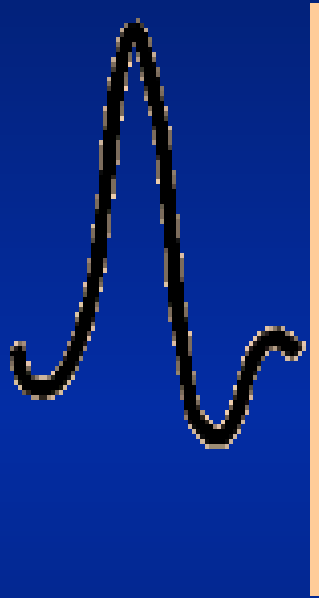
Reflection Coefficient

- Reflection Coefficient (reflectivity) $RC = \frac{\text{Amplitude of reflected wave}}{\text{Amplitude of incident wave}}$
- Consider the case of normal incidence

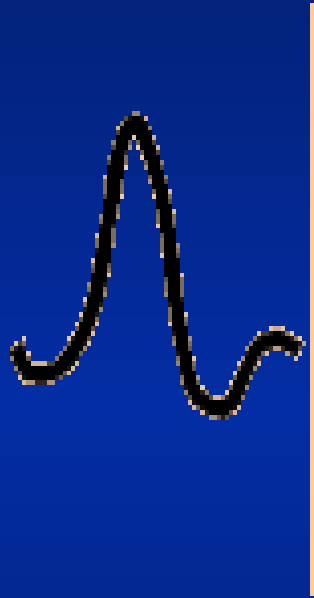


- At normal incidence: $RC = \frac{D2V2 - D1.V1}{D2.V2 + D1.V1}$
- The quantity DV is the **ACOUSTIC IMPEDANCE** of the material, which is the product of velocity and density of the material.

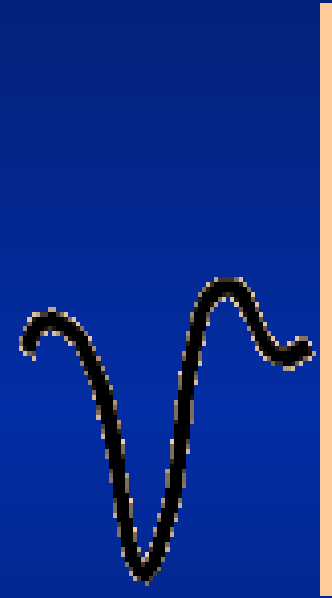
Reflection Coefficient



Incoming wavelet
RC= negative

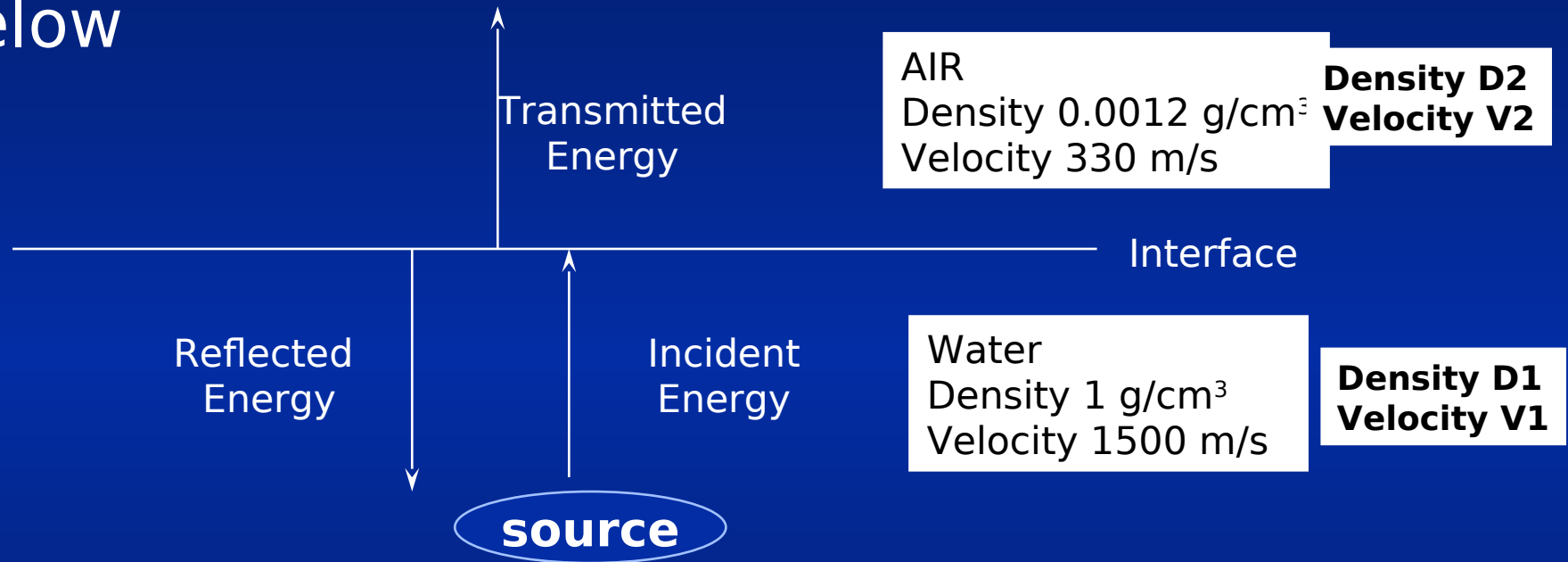


RC= positive



Reflection Coefficient - Example

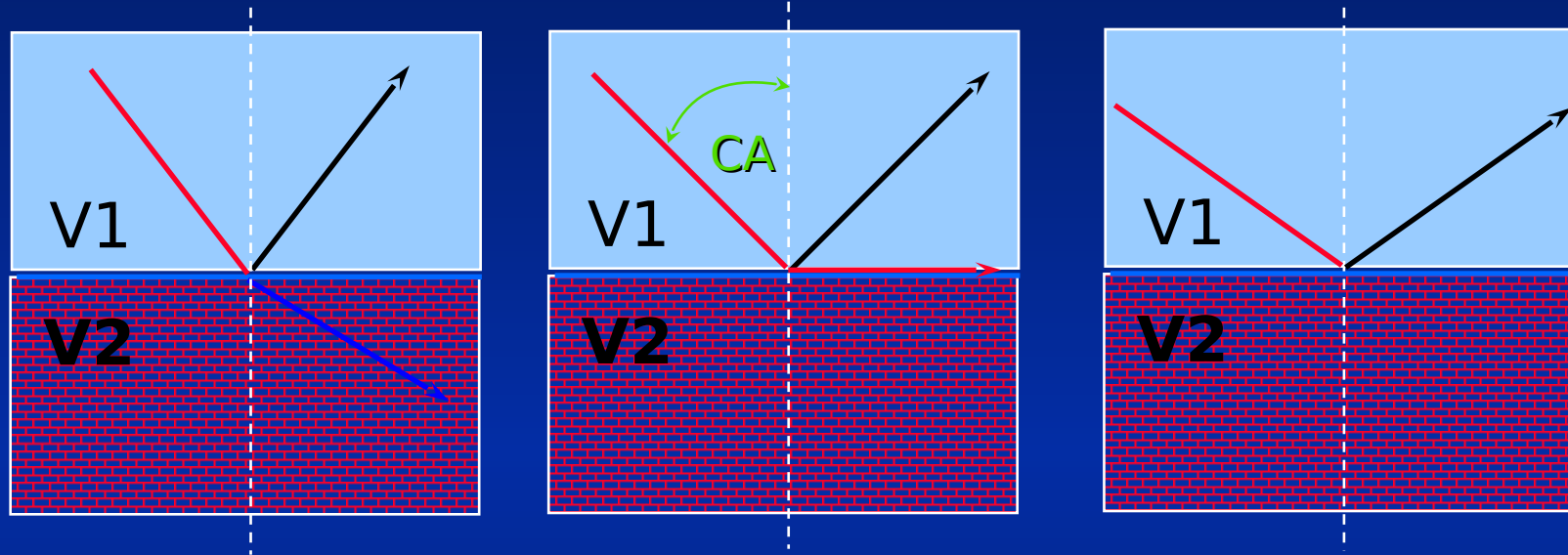
Wave incident on the water - air interface from below



1 implies: all energy is reflected and a phase change occurs (180 deg)

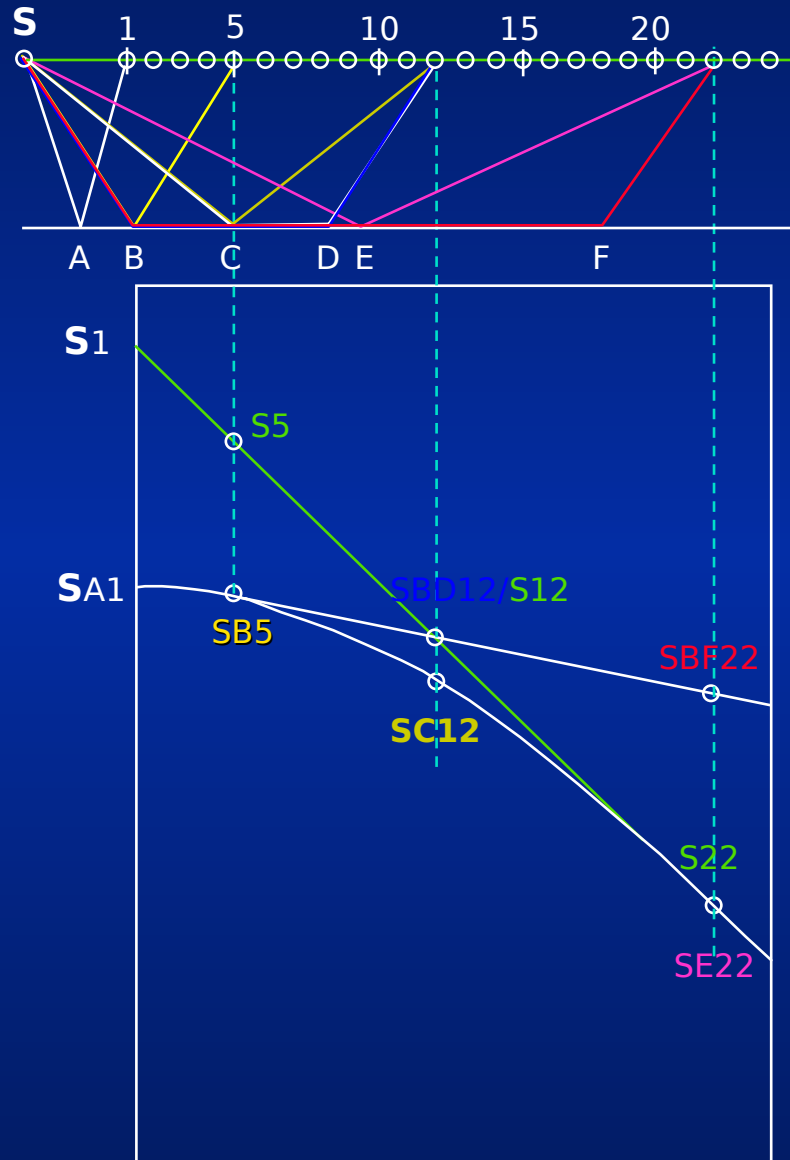
Critical Angle

In general $V2 > V1$ and refracted waves bend away from vertical



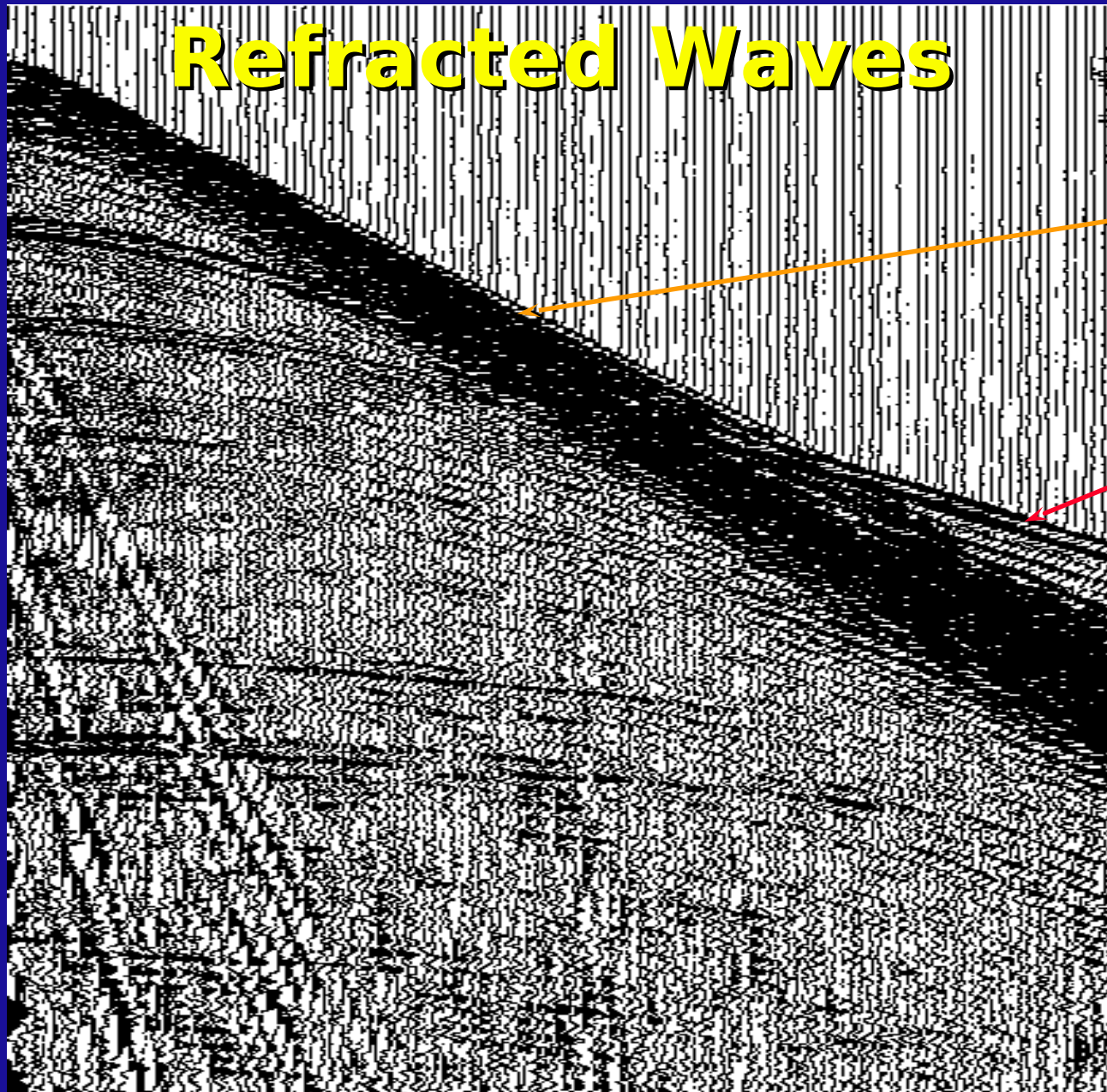
- As the angle of incidence increases, it reaches a critical angle, where a refracted wave will travel along the layer interface.
- At angles of incidence greater than the critical angle no incident energy is transmitted.

Energy Arrivals



A schematic of energy arrivals on an idealized shot file

Refracted Waves



direct
water-borne
energy

refraction
energy

Multiples



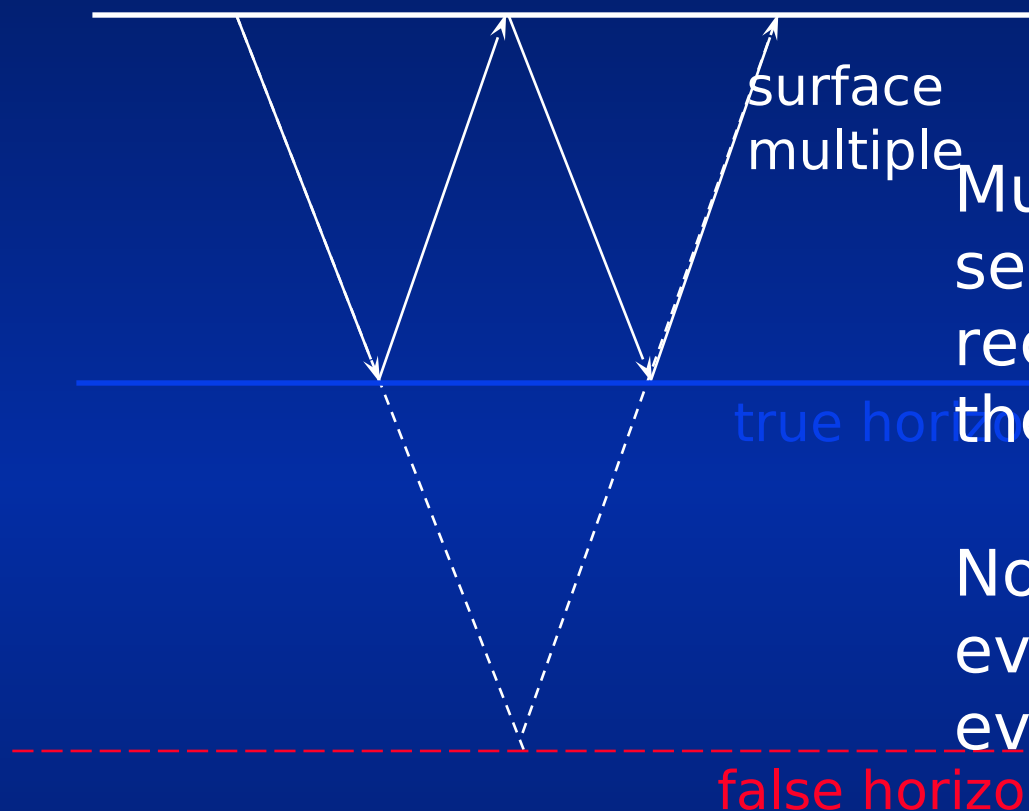
Seismic energy which travels from source to interface and is then reflected back to a detector produces a primary reflection.

If the energy is reflected more than once in its path to the detector then a multiple reflection is produced.

Multiples arise when there are interfaces with large reflection coefficients, i.e.

where there are large velocity and/or density changes. Examples: sea bed, sea surface or marine

Multiples



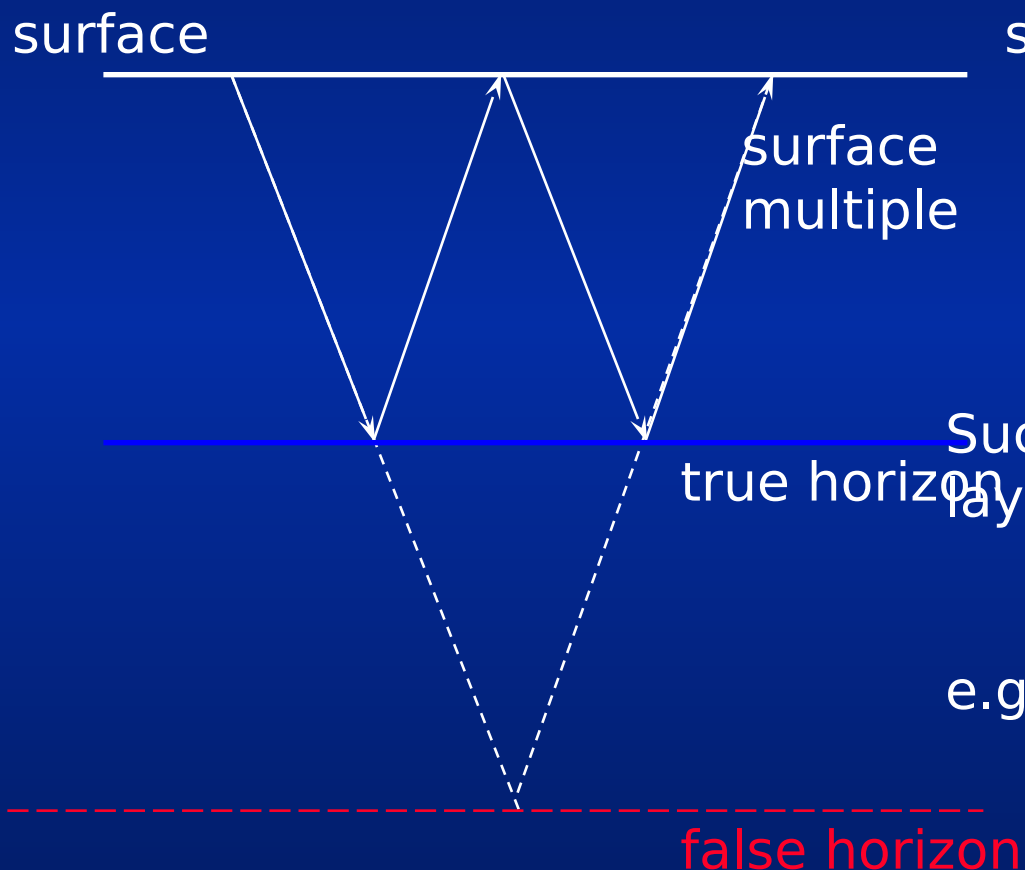
Multiple reflections give rise to false seismic events or horizons that are recorded and displayed along with the primary (true) events.

Note that the arrival time of the event will be twice that of the true event.

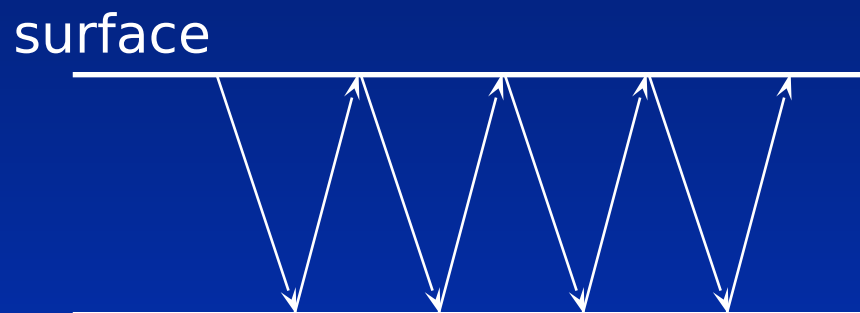
Simple multiple

Multiples

Long-path multiple
'easy' to remove



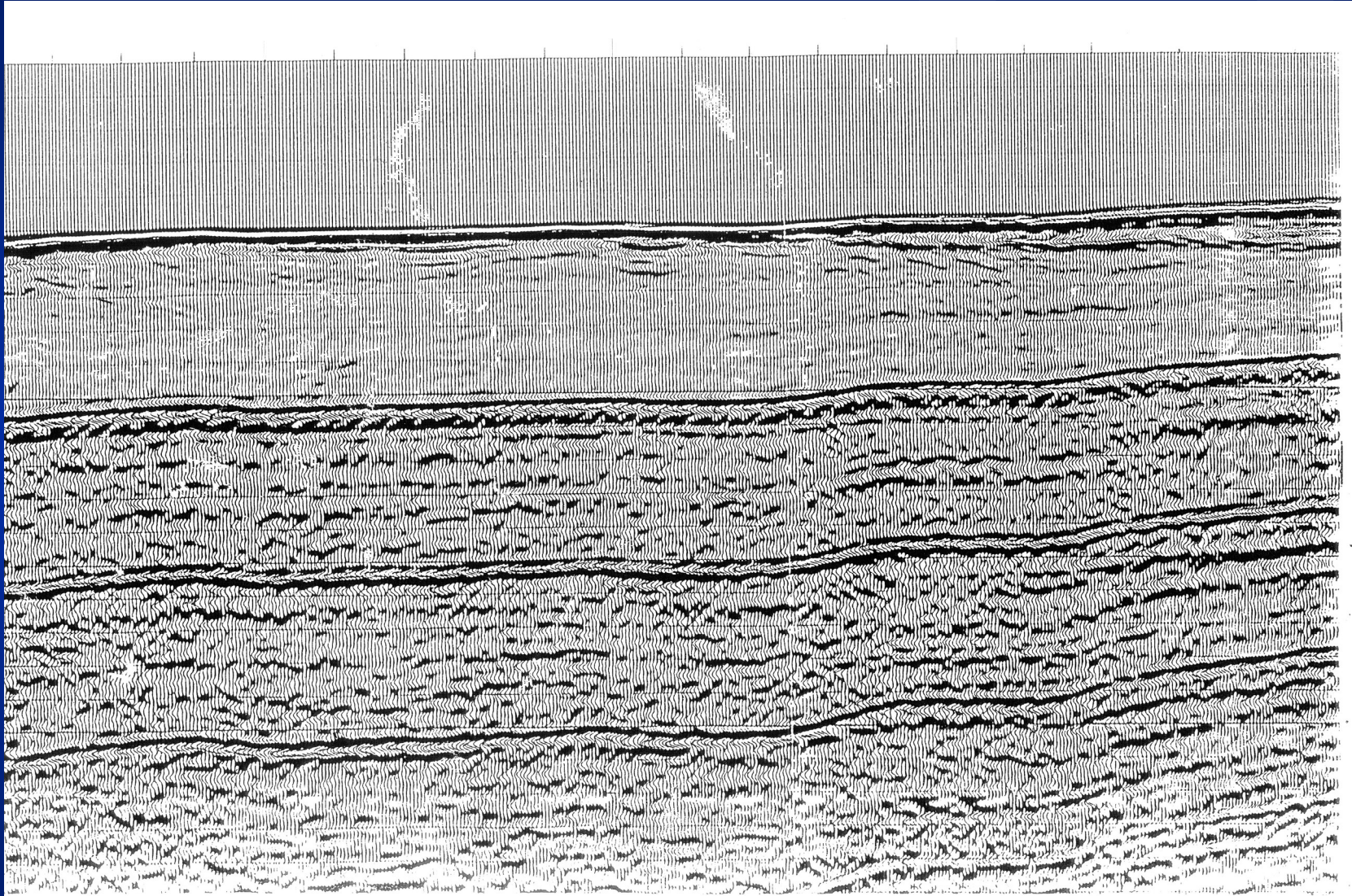
Short-path multiple
'hard' to remove



Successive multiples trapped in shallow layer blend together producing 'ringing'

e.g. reverberations in water layer
or in weathered layer on land

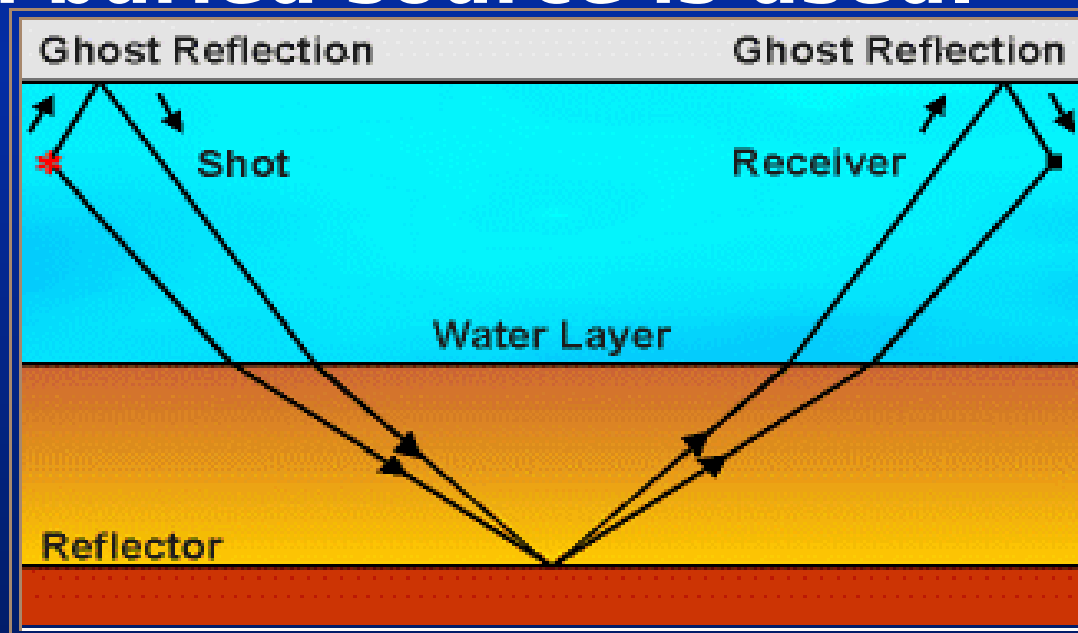
Multiples -



Sea Bottom Multiple

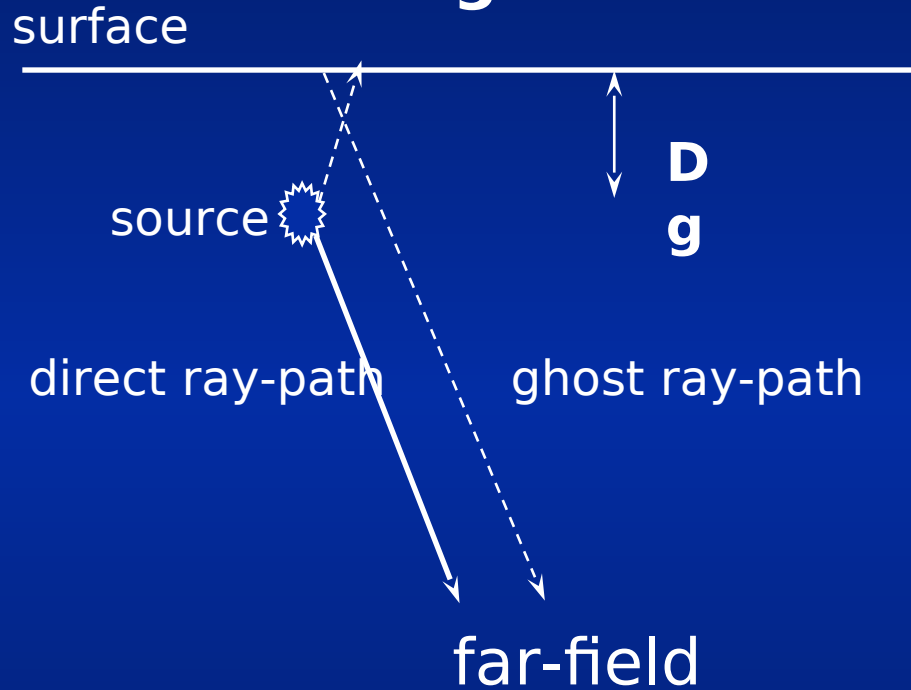
Ghosts

Energy which travels upward from an energy release and then is reflected back downward, such as occurs at the water surface in marine. It can also occur in land if a buried source is used.



Ghosts

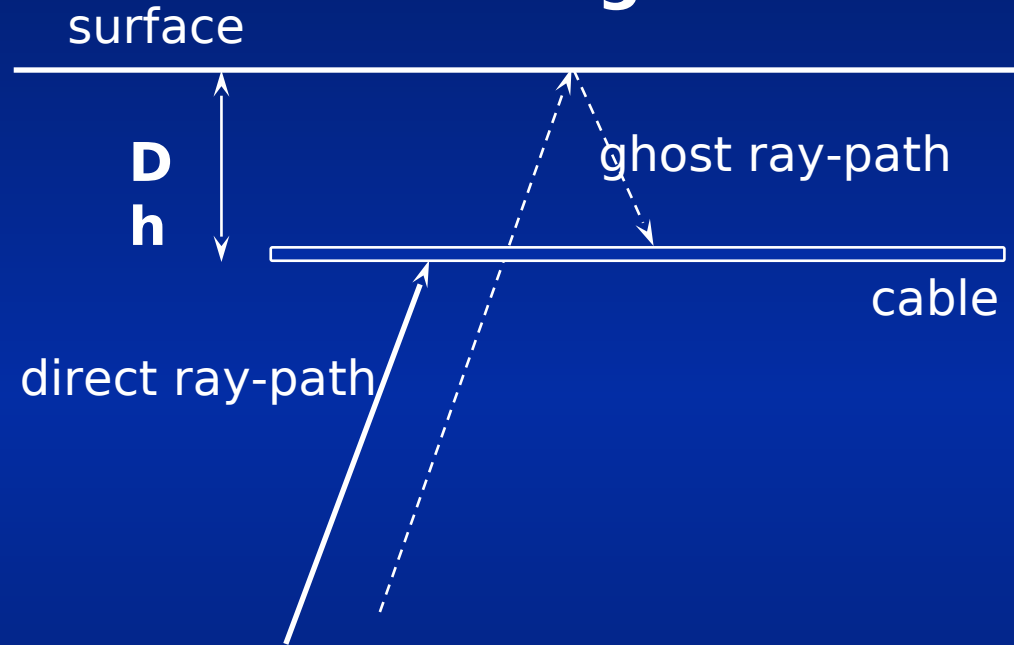
Source ghost



$$\lambda/2 = D_g \quad f_g = V/2D_g$$

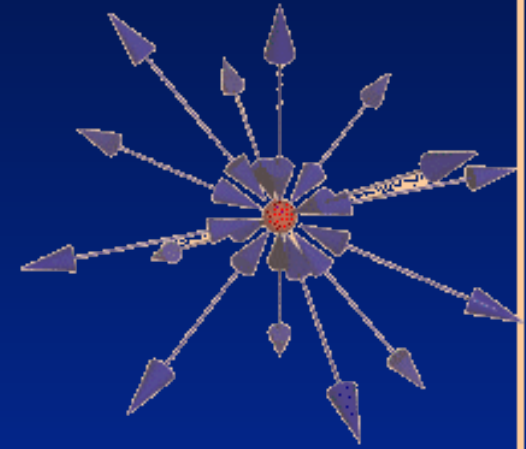
$$V = f\lambda$$

Receiver ghost



$$\lambda/2 = D_h \quad f_h = V/2D_h$$

Diffractions



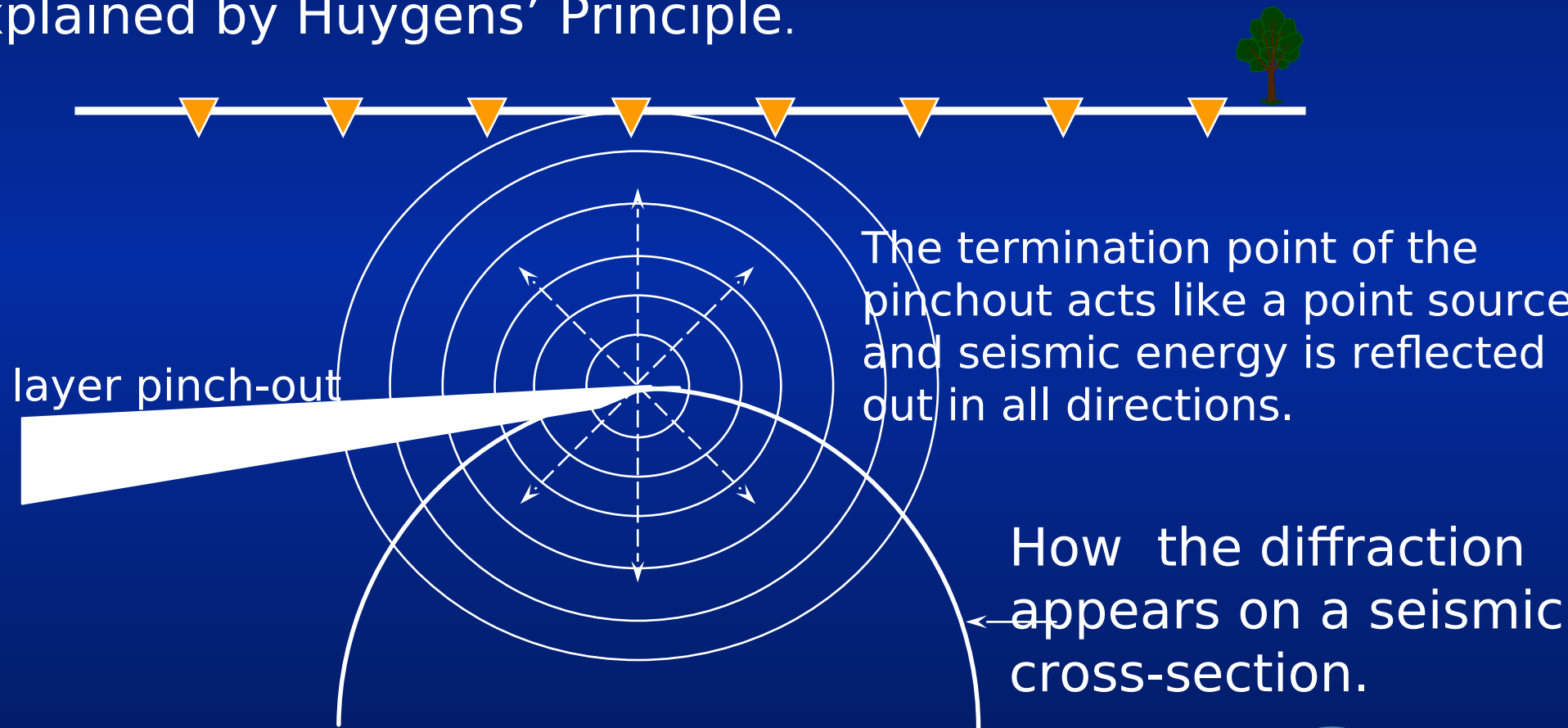
When a seismic wave strikes an irregularity, this feature acts as a point source and radiates waves in all directions, in accordance with Huygens's principle.

For example, an isolated point like the end of an interface that truncates against a geological fault, will scatter energy from all directions back towards its source.

Diffractions

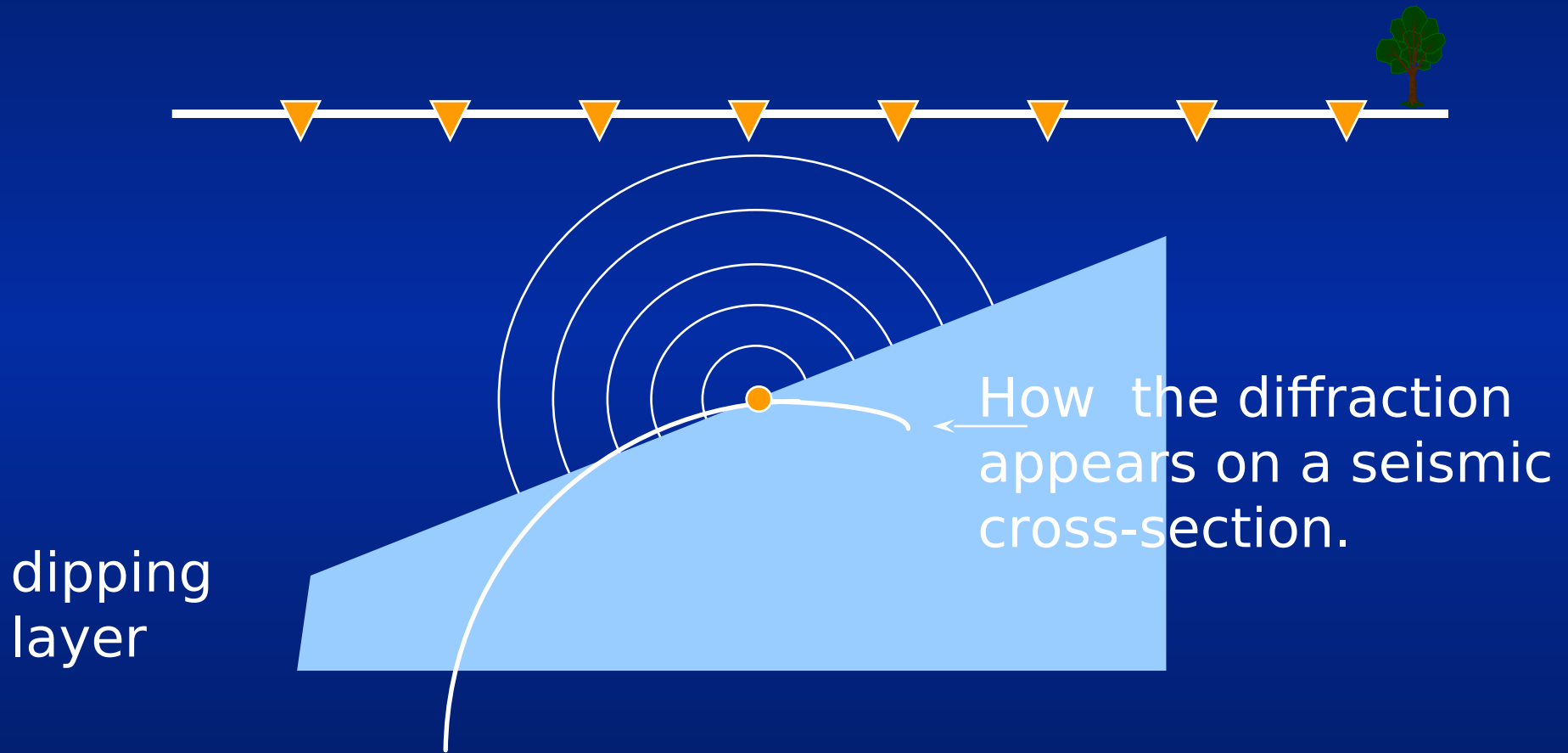
Seismic energy strikes discontinuities in subsurface interfaces and diffracts. Seismic waves are bent around the discontinuity.

This can be explained by Huygens' Principle.



Diffractions

At pinchouts, diffractions occur when seismic waves strike faults or interfaces.

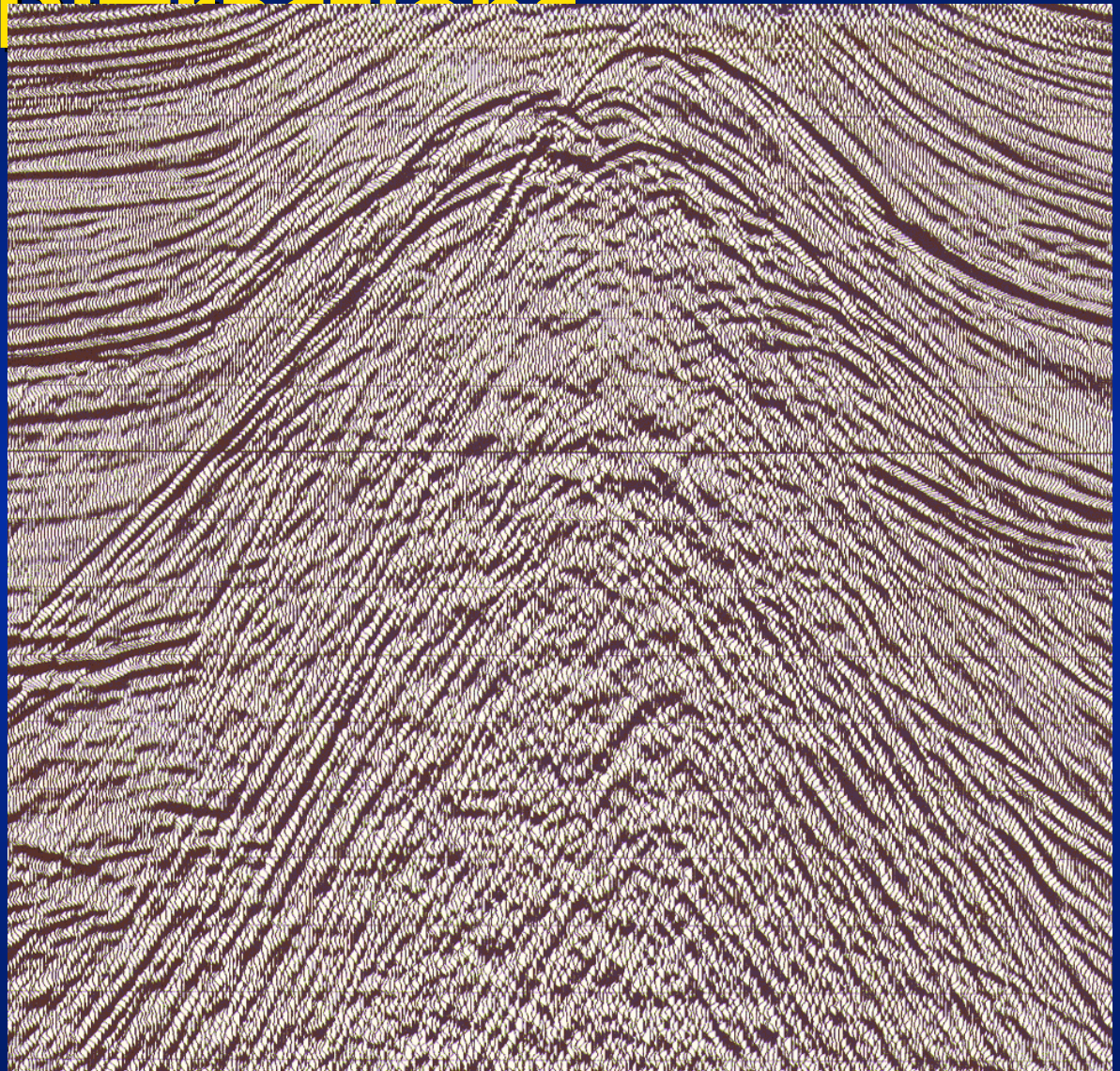


Example of Diffractions

In the seismic section, the appearance of diffractions is very similar to reflections from an anticline structure.

This has resulted in dry wells being drilled over what seemed to be hydrocarbon prospects.

Although diffractions may be considered in some cases to be 'noise', they contain useful information and energy which must be preserved.



Summary

